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ADP013870

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On the Possibility of Counteracting or
Reducing G-Induced Spatial Disorientation
With Visual Displays

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Summary

The possibility of counteracting or reducing g-induced spatial disorientation in fighter aircraft with visual displays is discussed in connection with the "classical" distinction between focal/ambient vision and inside-out/outside-in attitude display concepts. A relatively simple and uncomplicated laboratory method is presented that is utilized for exploring primarily visual flow coupling with spatial orientation. In part building on some experimental results from using the method some schematic implementation examples are illustrated, and some preliminary display design guidelines are also suggested.

Frames of reference

The controversial debate about what frame of reference we should use for attitude displays is still not entirely settled. The issue concerns whether to use an inside-out or outside-in representation, and the debate is almost entirely about its presentation in the central visual field. A review article by Previc and Ercoline (1999; see also Johnson & Roscoe, 1972) presents the various arguments for the two positions and shows that empirical results, overall, are in support of an outside-in format as the best candidate for reducing SD accidents. However, are we really optimizing the support of the pilot's spatial orientation with the substitution of one central visual field presentation with another?

It has now and then been argued that one shortcoming with cockpit instrumentation is precisely that it focuses on foveal or central vision (e.g., Leibowitz, 1988; Malcolm, 1984; Wickens & Hollands, 2000). This makes instrument information transfer dependent on directed attention and unsuited for direct perception of spatial orientation. Of course, this is not to deny the importance of the traditional flight instruments that represent the position of the aircraft relative the ground in various ways, e.g., horizontal gyro, altimeter, or head-up display (HUD) symbology. These instruments, however, require the pilot to direct attention to them, and are therefore in competition with other attention demanding tasks. Not surprisingly, the risk for SD accidents increases dramatically during low visibility when spatial orientation can only be maintained from intentional inspection of flight instruments. (Unrecognized SD - type I - is here of special importance.) Thus, although showing a potential for reducing some SD mishaps and fatal accidents, an outside-in instrumentation does not seem to be sufficient for really solving the problems of spatial disorientation.

This seems to leave us with a choice between research strategies, a choice between focusing research on: (1) "attention-requiring central vision interface principles", and (2) the mechanism for perceiving spatial orientation in every-day life. The first alternative could mean that we adopt the outside-in format and are more or less satisfied with this intervention. The second alternative challenges us to improve display characteristics to make the recreation of critical perceptual factors of the real visual scene realistic, optimal, and more effectively functional. The direct perception of spatial orientation relies on the characteristics of the whole ambient visual field and it is typically not dependent on attention. The

problem is therefore not just to provide efficient visual information about spatial orientation, but also to counteract possible influence on the normal mode of perceiving spatial orientation. For instance, the part of the cockpit available to the peripheral visual field provides information about no-change in spatial orientation.

This alternative specifically outlines the exploration of characteristics of a wide-angle display, or peripheral displays, with an inside-out format. Further, this strategy leaves the question open about what kind of format attitude presentation in the central visual field should have. A combination of inside-out/outside-in formats is therefore not unlikely. Thus, this could lead to somewhat of a new kind of "hybrid" attitude display or rather a combination of frames of reference: An outside-in representation in the central visual field (HDD, HMD or HUD) with an inside-out format presented in the visual periphery (HMD or HUD). If an outside-in format is implemented on existing HUDs it actually means a superimposition on the view of the real background world in conditions of good visibility of ground and horizon, and thus a natural version of this combination. In fact, this kind of presentation is conceivable in that "proponents of the outside-in format have argued that such a format is both flyable on the HUD and possibly even superior in this case as well" (Previc & Ercoline, 1999, p. 385).

The main point to be made, however, is that *we need a visual aid that better resonates with the mechanism normally underlying spatial orientation to significantly reduce or counteract SD*. That is, the pilot's perceptual processing needs to come in contact with the crucial factors of the natural situation of viewing ambient earth surroundings with horizon that cause spatial illusions to be overcome. *We need to reconstruct the dominance of vision in perceiving spatial orientation.*

Preliminary guidelines for an effective visual display interface

What visual factors then are contributing to the fact that there are relatively few aircraft accidents due to spatial disorientation when visibility is good? Again, the obvious factors are of course the stable ground/horizon with the motion generated optic flow (Gibson, 1979; Lee, 1980). The effectiveness of optic flow for maintaining spatial orientation has often been emphasized, and, among others, Flach and Warren (1995) have investigated utilization of its geometrical properties to support spatial orientation. Most probably due to technological shortcomings especially regarding implementation, however, these properties of the flow field have been presented predominantly in the central visual field (e.g., Flach, Warren, Garness, Kelly, & Stanard, 1997; see the WrightCAD display in Flach, 1999). By contrast, von Hofsten and Rosander (1997) insist on emphasizing the importance of stimulated visual periphery from presentation of similar optic flow information in a wide-angle display.

Can visual displays be constructed in such a way as to convey the crucial information that supports spatial orientation? Can we recreate the crucial information on visual displays to make it sufficiently effective in supporting the pilot's spatial orientation and thus reduce spatial disorientation mishaps? It may be unlikely that helmet mounted displays (HMDs) technically capable of presenting sophisticated wide-field views can be provided in cockpits in the near future. It is perhaps more plausible that we can implement some of the HUD principles to approach the benefit of real wide-field presentation. Then again, HMD technology is a developing field in focus by several interested parties.

Most critical is if and how "stability" is accomplished in order to get it firmly anchored as an external frame of reference, and thus induce "perceptual believability". This primarily involves the compensation of any movement of the pilot and aircraft with a sufficient temporal resolution, and together with good optic solutions, it will compellingly contribute to making it a background frame of reference. Spatial resolution or visual scene realism are not as critical if presented on peripheral displays on a HMD. For instance, consider Kappé (1997; and Kappé, Erp, & Korteling, 1999) in a successful attempt to improve visual perception in a virtual environment by adapting display characteristics to the properties of the visual system:

> "By means of a head-slaved display presented on three adjacent displays, a detailed image can be presented in the viewing direction, surrounded by a sparse peripheral image on the remaining area of the displays…Clearly, peripheral displays had a positive effect on driving performance and spatial orientation,

even though they presented a relatively small amount of information. A peripheral display presents information to the ambient visual modality, which improves (ego) motion perception and spatial orientation. In the present study, both the head-slaved display and the peripheral display presented the same virtual environment, albeit at a different level of detail…The results of the present experiments show that display effectiveness can be improved by adapting display characteristics to the properties of the visual system. Changing the virtual viewing direction is an effective method of increasing the field of regard, but is only effective when the images are presented at their proper position in the optic array, for instance by use of a head-slaved or head-mounted display…A head-slaved display surrounded by a sparse peripheral image was found to be just as effective as a wide-field three-channel display."

Kappé, 1997, pp. 36-37

This implies that we do not have to use a sophisticated, wide-angled full-view connected HMD, but instead can use *three separate fields-of-views ("display surfaces") with the two peripheral ones presenting an artificial horizon and optic flow with (quite) sparse detail (lower resolution).*

A methodological attempt: Trying to get there!

In order to generate guidelines for an optimal design of the visual interface some of the basic parameters for exploration have to do with how much of the visual field needs to be covered by the display. For instance:
1.   How much information needs to be presented in the central visual field?
2.   How much of the peripheral field needs to be employed?

In general, these issues could be investigated by using human centrifuge settings where the g-force varies while visual vertical is constant, i.e., Dynamic Flight Simulator with visual presentation of parts of a surrounding environment. These are more of ultimate test situations, however, and it is more practical to manipulate the visual vertical and keep the g-force constant, a situation easily accomplished in the laboratory by presenting a visual flow to subjects wherein the visual vertical varies. In this way, we are trying to obtain key indications of the effectiveness of various visual factors, and later evaluate those in the Dynamic Flight Simulator.

The rationale is that the importance of the visual determinants relative to the ones based on the g-force (proprioception and equilibrium sense) can be measured by its effect on balance. By varying the presentation of visual flow in combination with a moving horizon and study their effects on postural responses, we thus get indications of what properties of the visual display are effective in the perception of spatial orientation. Thus, our methodological approach so far is a relatively simple and uncomplicated laboratory method in which we evaluate how effectively different visual display factors affect the perceived equilibrium of the body. This is done by measuring the amount of sway induced when visually simulating different transformations of body orientation.

In the experimental situation the participant is positioned in an erect stance in front of three integrated computer monitors, with the monitors displaying simulated flight by motion of ground and horizon of a visual scene as viewed from a banking or rolling aircraft. The postural responses are measured by means of a head-tracker system that registers the 3-D changes of the participant's head position.

The computer monitors are connected and positioned so that the displays cover an integrated visual field of 150° horizontally and 34° vertically, including gaps between displays of 7.5° horizontally. See Figure 1. The basis for the visual stimuli is a flat virtual landscape with texture element gradient towards a clearly defined horizon beneath a starry sky, schematically shown in Figure 2. The fields of view of this virtual environment presented on the displays are determined by the position of the viewpoint as indicated in Figure 1, and they are constant throughout the presentations, i.e., the presentations are not head-slaved.
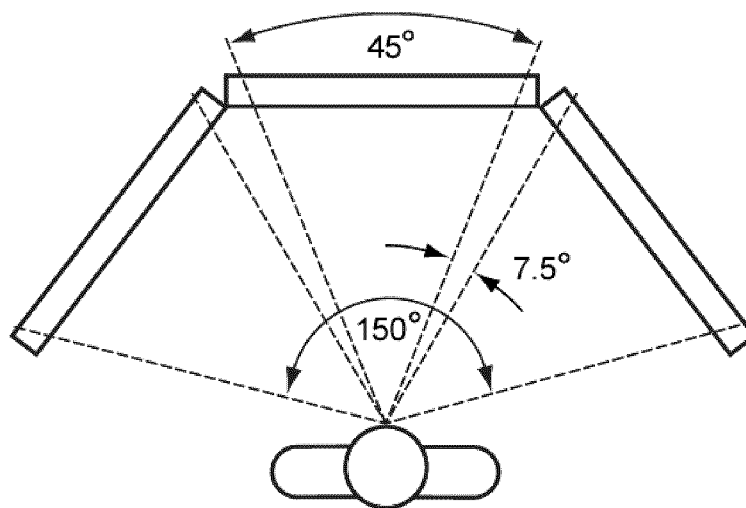
Figure 1. Top view of the visual fields covered by the display surfaces of the computer monitors.
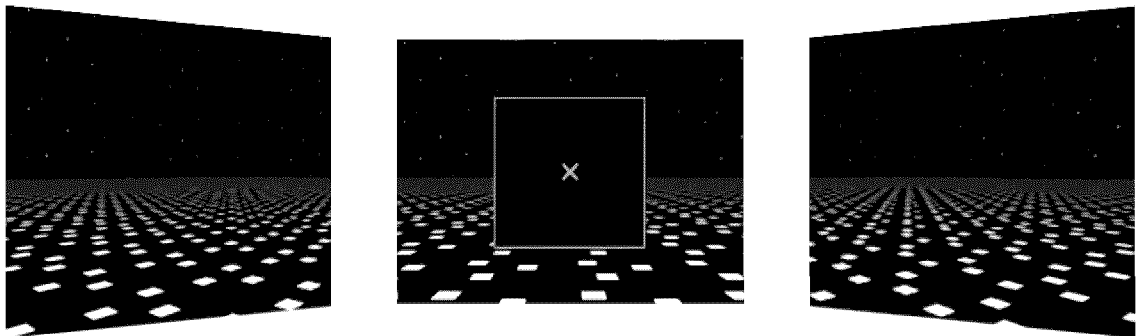

Figure 2. The virtual environment with ground and horizon presented on the display surfaces.

The height position of the display configuration is adjusted so that a horizontally positioned horizon line of the stimuli is at eye level, and the distances from observer's eyes to display surfaces are controlled to ensure accurate visual fields that the displays subtend. The participant is told to keep as still as possible while positioned in the "Sharpened Romberg Stance" and fixating the display center during the presentation trials. The employed stance is an erect stance with one foot in front of the other heel to toe, hands placed on the chest, and with the center of gravity kept approximately between the feet.

Figure 3 illustrates the geometrical axes for some postural instability measures in relation to observer position. For the postural instability measures we use the mean change computed from the registered changes in each roll (or bank) motion sequence – from start of roll to back to horizontal.
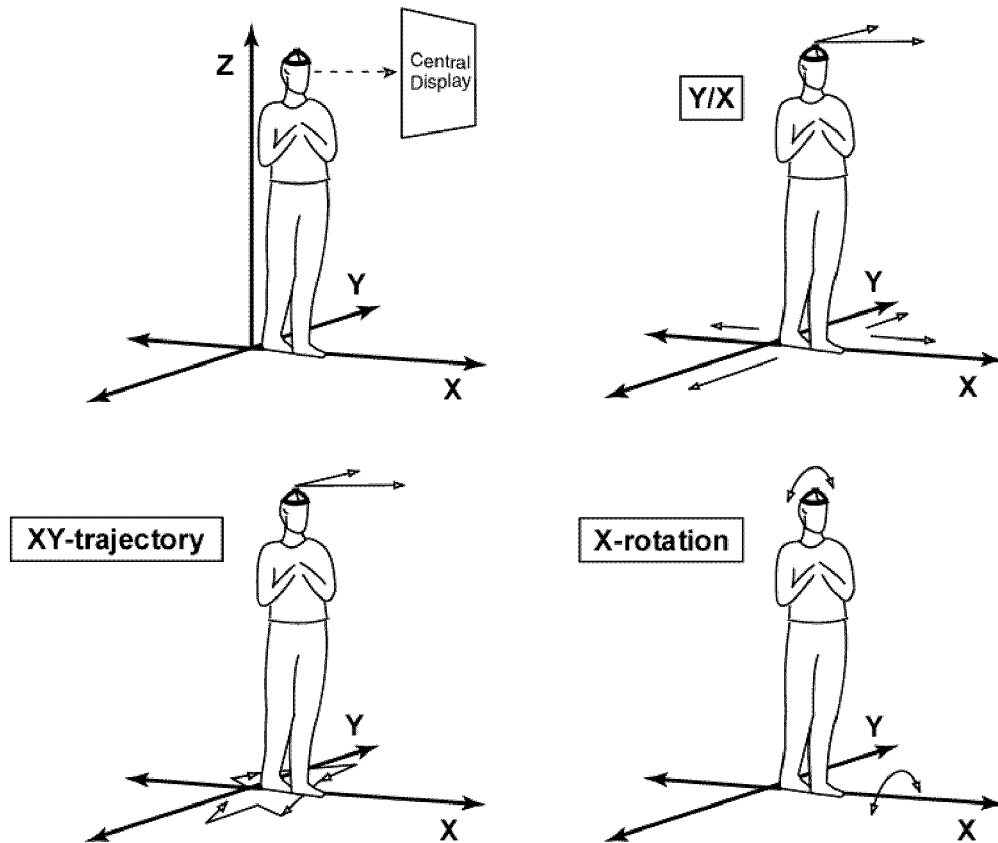

Figure 3. The geometrical axes for measures of postural instability in relation to observer position.

We expect that this method will provide us with results for extracting some display design guidelines regarding efficiency in resonating with the mechanism for spatial orientation. Further measures of performance, especially evaluation of aircraft maneuvering, with variations of such a visual interface are under planning, and these have to include experimental environments with both fixed and moving platforms. The intention is to use the Dynamic Flight Simulator here as well. Thus, again, we try to optimize a visual interface in the laboratory for later evaluation in a moving platform where the g-force can be varied.

Examples of implementation

In part building on experimental results from using the method, some basic illustrations of examples of implementation on HUD and peripheral HMDs are presented in Figure 4. These examples show an inside-out representation on both HUD and HMDs, as well as a combination of an outside-in HUD symbology with an inside-out format of artificial horizon with ground on HMDs.
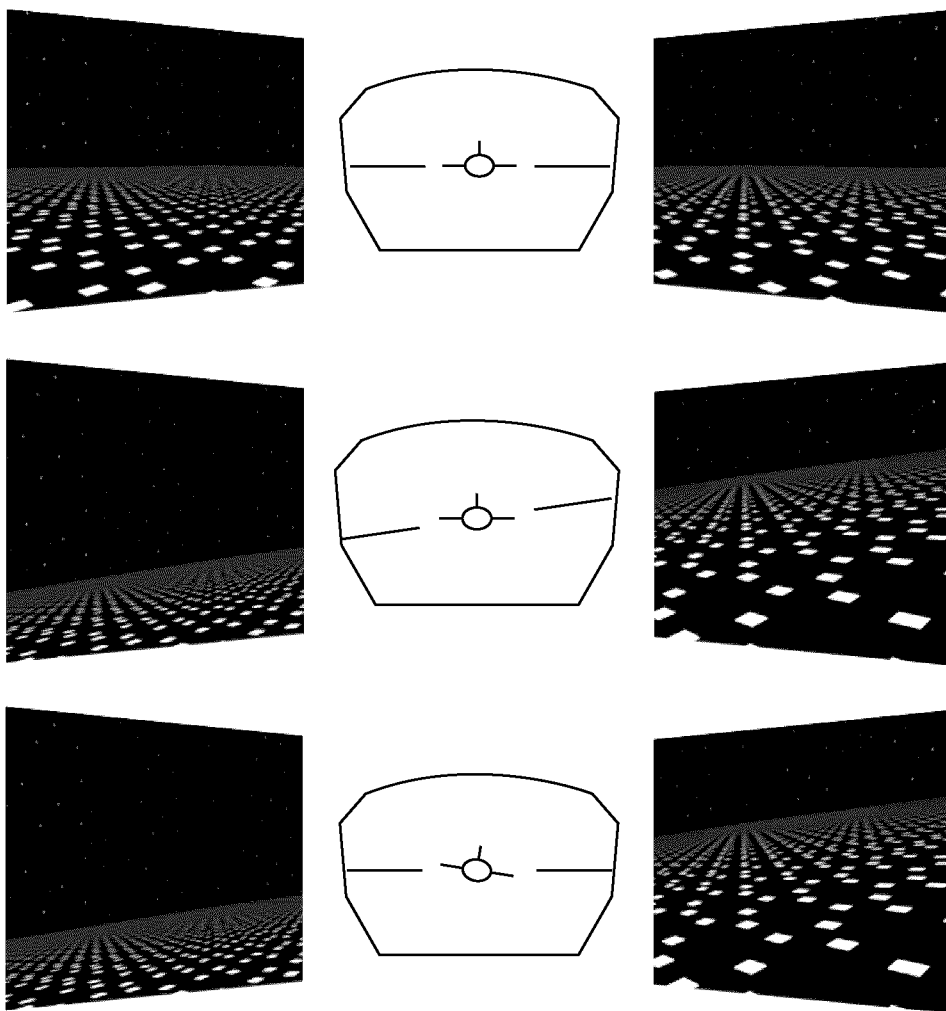
Figure 4. Illustrations of some schematic implementations from top to bottom: A "neutral" horizontal position with peripheral HMDs and a central HUD symbology, inside-out representations on both HUD and HMDs, and an outside-in format on HUD with inside-out HMDs.

Concluding remarks

The experiments have so far shown that decreasing the peripheral field down to 105° horizontally does not decrease the effectiveness of an ambient display for spatial orientation. Neither does the omission of a central area as large as 20° x 20° decrease the effectiveness of it. This means that such a display does not interfere with the task of keeping up with the various HDDs.

The spatial orientation displays could either be implemented as peripheral HMDs or HUDs. Both kinds of implementations pose problems that have to be solved before the display will be effective. The display has to provide the pilot with a simplified but correct view of the orientation of the outside world relative to the aircraft and how it changes over time. To be anchored in the outside world means that a HMD has to fully compensate for head movements of the pilot in addition to showing the movements of the aircraft. A HUD could be implemented on the sides of the cockpit. It has to compensate for any movements of the pilot relative to the cockpit in addition to showing the movements of the aircraft. In other words, if the pilot moves to the left more of the virtual world on the left side of the cockpit should be visible and less of the world on the opposite side in the same way as in a situation with good visibility. The choice of the mode of presentation has to be guided by the criteria of robustness, reliability and simplicity.

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